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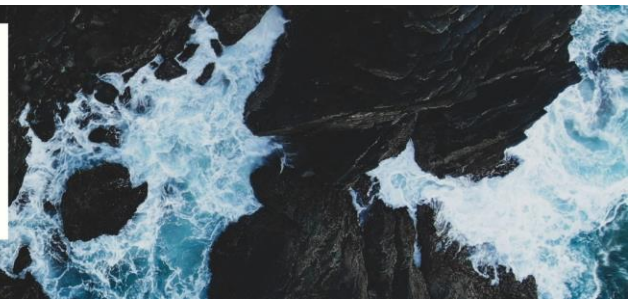
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Numerical simulation of the ground thermal storage of solar heat through an energy wall system

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Summary

Technological advancements are essential for decarbonizing the heating and cooling sector, and energy geostructures can play a significant role in this effort. These structures utilize the underground as a heat reservoir that can provide heating during winter and store excess heat from buildings during summer. At the Politecnico di Torino, a prototype of an underground energy wall, called GeothermSkin, has been realised in 2019. The prototype is being enhanced by connecting the energy wall with the solar thermal collectors (and related storage tanks) to explore low and high-temperature underground heat storage and study the thermal recharge of the ground using the geothermal circuits. A 3D thermo-hydraulic numerical model has been created to investigate the feasibility of this system and preliminarily understand how the storage temperature and duration could affect the system's performance. After calibrating the geothermal properties of the subsoil, various operating scenarios have been considered to identify the most effective storage modes.

1 Introduction

The heating and cooling sector plays a crucial role in helping the European Union (EU) achieve its energy and climate targets. Currently, it accounts for nearly half of the EU's total gross final energy consumption, which is still predominantly derived from fossil fuels [1]. Given the significant rise in energy consumption and carbon emissions, it has become essential to adopt innovative solutions that harness and store renewable thermal energy. In this framework, on one side, in recent years, energy geostructures have gained considerable attention due to their dual function as structural supports and heat exchangers, enabled by the installation of absorber pipes for geothermal energy exploitation [2]. These systems are expected to be vital in the coming years, particularly because they can be applied in urban settings and in either new or existing constructions [3]. On the other side, solar thermal energy is an effective, market-ready option for space heating; however, its intermittent nature requires its storage during periods of excess production to prevent heat wastage. To address this, energy geostructures could be exploited to store excess heat coming from periods of abundance, while also enhancing the performance of the energy geostructure itself, during the heat extraction phase. To provide insights of the behaviour of an existing energy geostructure, specifically a shallow energy wall, integrated with solar thermal energy circuits, a 3D thermo-hydraulic model of the GeothermSkin prototype [3] was built to perform numerical analyses assuming different operating

conditions.

2 The prototype GeothermSkin

The concept of GeothermSkin was developed with the objective of equipping the earth-contact surfaces of all kinds of construction (either new or existing) to provide full or partial fulfilment of their renewable energy requirements, while minimizing the installation-related costs and with no horizontal area occupancy [3]. In this solution, the geothermal circuits are applied to the surfaces as a skin to transform the underground storeys of buildings in geothermal collectors. A prototype of such system has been installed in 2019 on a shallow underground wall of the Energy Center building (in the Politecnico di Torino's campus, in Turin, Italy), which was already operative at the time of the realization. Three circuits with different deployment (2 horizontal and 1 vertical) were fixed on the bared surface using metallic clamps with 75 cm spacing. Each circuit corresponds to one module of the concrete wall of 2.50 m length and 4.60 m height. The hydraulic circuits adopted in the three modules are made of crosslinked polyethylene (PE-Xa) and have an external diameter of 20 mm, a pipe wall thickness of 2 mm. The nominal thermal conductivity and roughness are equal to 0.38 $W \cdot m^{-1} \cdot K^{-1}$ and 0.007 mm. The branches of each circuit have a spacing of 30 cm and the heat carried fluid circulating in the pipes is a mixture of water and 25 % propylene glycol, to ensure safe operation within a temperature range down to the mixture's freezing point of -10 °C. It is also possible to test singular or more modules thanks to the presence of ball valves positioned at the onset of each geothermal loop. The operation of the system to supply the heating and cooling demands is managed by a ground-source heat pump to which the primary (PE-Xa pipes) and the secondary (galvanised steel pipes of 28 mm external diameter) circuit are connected. The prototype is being enhanced by connecting the energy wall with the solar thermal collectors (and related storage tanks) to explore low and high-temperature underground heat storage at specific times.

3 Enhancement of the energy wall performance with underground heat storage

A 3D thermo-hydraulic model was built in COMSOL Multiphysics® software v. 6.2 [4], reproducing the two geothermal modules characterized by a horizontal layout of the pipes with sequential linking. The heat exchanger pipes were represented by 1D elements to which the pipe's wall thickness, roughness and thermal conductivity were assigned. Following the numerical procedure explained in [5], monitoring data (referring to the heat carrier fluid and ground temperatures) collected during previous experimental campaigns [3] were used to calibrate the soil's geothermal properties. These are indicated in Tab. 1 together with the thermal properties adopted for the wall's concrete and heat carrier fluid (water-glycol mixture at 20 °C, which corresponds to the average fluid's inlet temperature, considering whether heating or cooling tests). The geometry of the 3D model and the applied boundary conditions are shown in Fig. 1.

Table 1: Thermal properties adopted in the numerical model

	Subsoil, layer 1	**Subsoil, layer 2**	**Subsoil, layer 3**	**Concrete**	**Heat carrier fluid**
Thermal conductivity [$W \cdot m^{-1} \cdot K^{-1}$]	1.41	0.75	2.48	1.12	0.47
Specific heat capacity [$J \cdot kg^{-1} \cdot K^{-1}$]	790.35	860.6	860.6	916.9	3917
Density [$kg \cdot m^{-3}$]	2224.08	2224.08	2224.08	2388.46	1023.44

After the calibration of the thermo-hydraulic model, numerical analyses were carried out to explore the performance of the energy wall with low and high temperature underground heat storage at different times.

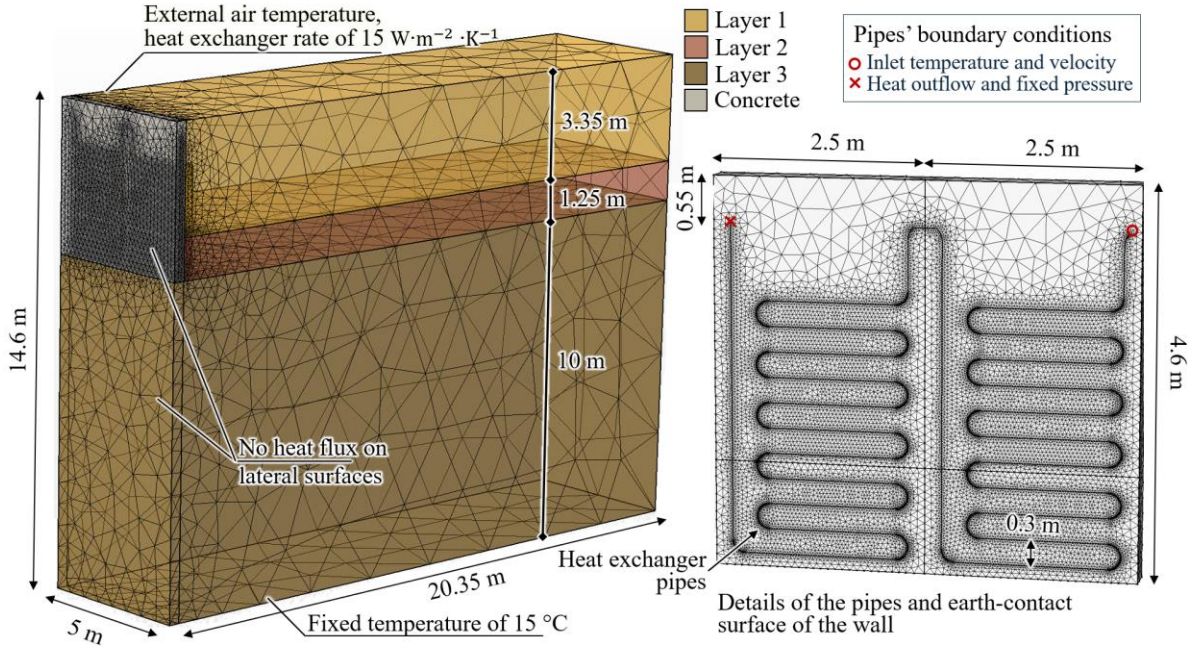


Figure 1: 3D thermo-hydraulic numerical model with the detail of the two prototype modules with pipes deployed horizontally and indication of the boundary conditions.

Firstly, the underground temperature distribution in the model was reproduced by applying Turin's monthly external air temperature for three years and half (from January until the beginning of June) without any heat flux occurring within the pipes. During summer, 3 scenarios were analysed for the operation of the energy wall: no operation (A1), 4 months of cooling (pipe inlet fluid temperature of 28 °C for 7 h a day, named A2); 4 months of heat storage (pipe inlet fluid temperature of 60 °C for 7 h a day, named A3). For each case, four operation modes were assumed for the winter's operation of the geostructure, all of them including a 13 h long daily heat extraction phase. The winter scenarios are differentiated based on the activation of the energy wall at night. In the first mode (B1), the energy wall was not active at night. In the other modes, the energy wall was utilised for underground heat storage (for four hours) at different temperatures: 25 °C (B2), 35 °C (B3), and 55 °C (B4). The thermal energy extracted using the energy geostructure at the end of the entire winter season and in all the examined scenarios is indicated in Figure 2.

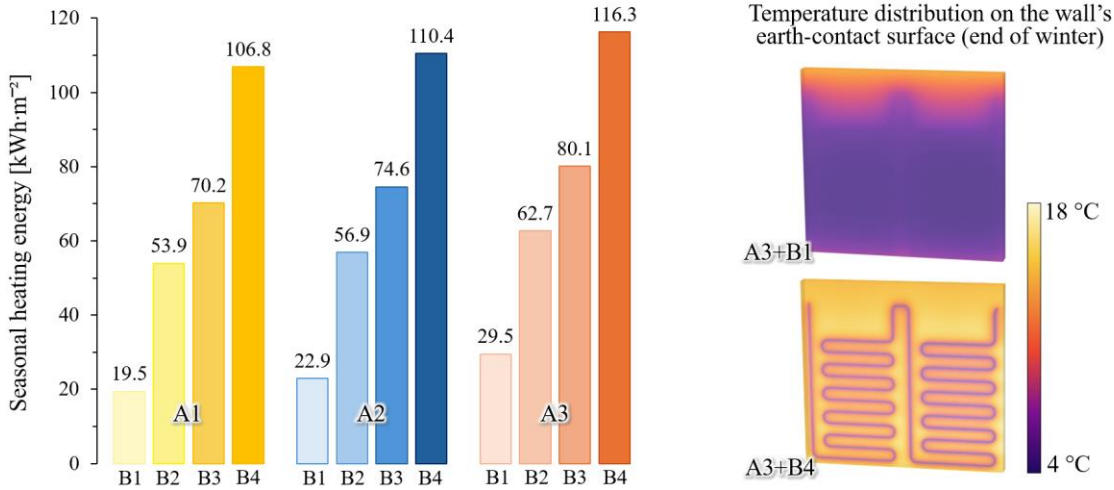


Figure 2: Seasonal thermal energy computed at the end of winter for each scenario (left) and temperature distribution on the wall's ground-contact surface at the end of winter (right).

When the energy geostructure is not used for heat storage during winter (B1), the amount of geothermal energy exploited at the end of winter increases by more than 17% (A2+B1), if the energy wall was previously used for summer cooling or by more than 50% if the energy wall was previously used for summer heat storage at 60 °C (A3+B1) compared to the situation without any summer operation (A1+B1). However, the operating modes that proved to be more advantageous, in terms of thermal energy extracted during the heating season, are the ones that adopt daily winter heat storage (B2, B3, B4). In all these cases, in fact, the performance of the energy wall increases by more than 100% compared to the scenarios with identical summer operation (A1, A2, A3) but without daily winter heat storage (B1). As expected, the major improvements are achieved when the winter nightly inlet temperature of the fluid is the highest (i.e. 55 °C, mode B4).

4 Conclusion

Numerical analyses were carried out to predict the future performance of the combined GeothermSkin and solar collector system assuming different operating condition to anticipate the best scenario for future experimental tests. Despite the shallow depths of the underground wall, the results obtained demonstrate that underground solar heat storage performed by means of the energy wall is a feasible solution to enhance the geostructure's performance in the following heat extraction phase, especially if there is the possibility of storing heat in the heating season too.

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